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ASIAN MONSOONS OBSERVED BY THE SCATTEROMETERS AND COMPLEMENTARY SPACEBASED SENSORS

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1. INTRODUCTION

Monsoons are the seasonal changes of winds forced by continent-ocean temperature contrast. Their annual onset, intensity, and retreat vary greatly, and the variation has strong economic impact and may cause severe human suffering. While the impact of the variation is locally felt, the cause of the variation is perhaps seeded in planetary waves [Lau and Li, 1984]. Beside bringing rain to land, monsoon also changes ocean currents and upwelling [Liu et al. 1992]. Over land the consequences of monsoon are, perhaps, well observed, but the breeding ground over the ocean has been insufficiently monitored. The lack of observations is particularly evident in the South China Sea (SCS).

'I'he SCS is a semi-closed ocean basin whose circulation is largely driven by the seasonal change of wind. We know relative little beyond that because of the lack of observations; the last published comprehensive survey dated back almost four decades [Wyrtki, 1961]. However, the SCS is at the crossroad of major climate systems. It is situated between the land masses of Asia and Australia and between the warm pool of the western Pacific and the Indian ocean. It is well known that the SCS Monsoon is a main component of the Asian monsoon system; it summer onset is ahead of both the Indian monsoon and the monsoons in China and Japan [Tao and Chen, 1987]. Its annual vacillation is significantly affected by the intensity of intraseasonal activities [Wang and Xie, 1997] and phase locked with the El Nino and Southern Oscillation [Yasunari, 1991].

Spacebased data which have become available recently provide more adequate coverage at the appropriate temporal and spatial scales to improve the monitoring of the changes in the SCS and its vicinit y.

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2. DATA

The microwave scatterometer is designed to measure both wind speed and wind direction under both clear and cloudy conditions over the global ocean [Liu and Tang, 1997]. The scatterometer on the European Remote Sensing (E RS)-1 was launched in 1991 and has continued to make wind measurements at 50 km resolution through its successor on ERS-2. The National Aeronautics and Space Administration (NASA) scatterometer (NSCAT) was launched in August 1996. NSCAT provides wind measurements over 78% of the ocean every day. NSCAT provides more than twice the coverage of the scatterometer on ERS1 and ERS2, and its measurement has spatial resolution of 25 km. The wind speed and direction used in this study are derived from both scatterometers and interpolated by Tang and Liu [1996] through a successive correction method.

The 'Topex/Poseidon altimeter [Fu et al., 1994] measures sea level variation along ten-day repeated ground-tracks; the data used in this study are resulted from objective interpolation to uniformly gridded field of 1° latitude by 1° longitude and 3 day resolution. The Advanced Very High Resolution Radiometers (AVHRR) on the operational polar orbiters of the National Oceanographic and Atmospheric Administration (NOAA) provide measurements of sea surface temperature (SST). Various forms of SST derived from AVH RR data are available. The SST data used in this study are from the seven-day composite compiled by blending AVHRR data with in situ measurements [Reynolds and Smith, 1994]. A number of Special Sensor Microwave / Imagers (SSM/I) on the operational spacecraft of the Defense Meteorological Space Program (DMSP) have monitored wind speed, precipitable water (PW) and liquid water since July 1987. Daily, 0.25° latitude by 0.25° longitude PW provided by Remote Sensing System in Santa Rosa [Wentz, 1983] are used in this study.

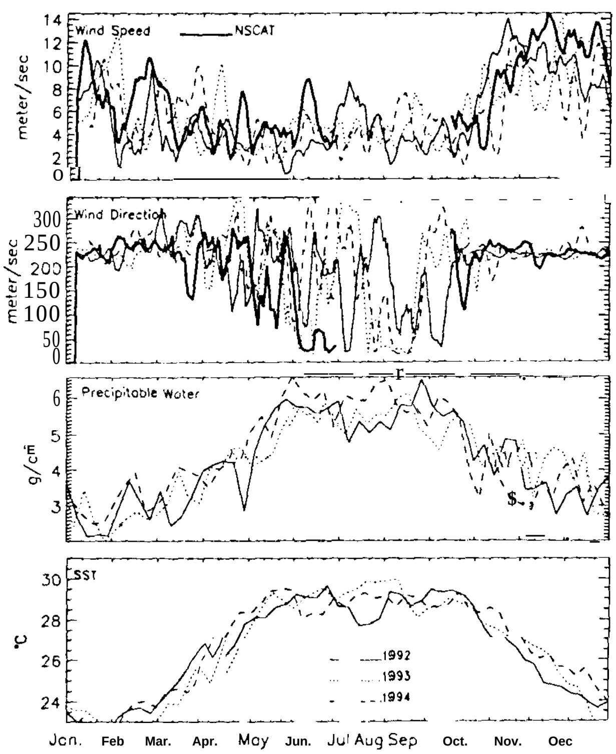

Figure 1: Annual variations of (from top to bottom) surface wind speed, wind direction, precipitable water, and sea surface temperature derived from space-based observations at 115°E and 19" N, off the South China coast, for various years. The wind speed and direction from NSCAT from September 1996 to June 1997 are superposed on measurements by ERS-1 scatterometer from 1992 to 1994 for comparson.

3. ANNUAL CYCLES

The annual cycles of some of the spacebased data at 19° N, 115°E for three years are shown in Fig. 1 as examples. In the three months between March and May, SST rises continuously from 24° C to 30" C in northern SCS, indicating the annual northward marches of warm water in spring, with no abrupt change, as shown in Fig. 1. This is true for the entire longitudinal section along 115°E, (not shown) from the South China Coast to Indonesia. The PW rises with SST, as shown in the same figure, but, there is a jumps in PW in May which is the most clear indication of the onset of summer monsoon. The values of SST and PW flatten out after May, or even decrease slight ly during the peak of summer monsoon. There is no clear sharp increase in wind speed to signal the onset of summer monsoon. The wind direction fluctuates considerably more during summer. The fluctuation may reflect strong intraseasonal weather activities. The onset of winter monsoon in October, on the other hand, is clearly reflected in the sharp increase in wind speed and in the steadiness of wind direction (from the northeast). There are corresponding drops in PW and SST following the onset of winter monsoon.

The winds and sea level have more latitudinal variations and their time-la atitude variations along 115°E are shown in Fig. 2 and 3. The southwest monsoon is represented by positive values in both zonal and meridional wind components, and the northeast monsoon is represented by negative values in both components, as shown in Fig. 2. The onset of summer monsoon takes place in early May and there is very little latitudinal dependence. The onset of winter monsoon, on the other hand, has clear latitudinal dependence; it takes place about one to two month earlier in the South China coast than at Indonesia. The seasonal changes of sea level and implied ocean circulation are also clearly revealed in Fig. 3. In summer, an elevation in the center of the ocean basin implies cyclonic geostrophic current, and an depression in the center of the basin implies anticyclonic geostrophic current in winter.

Annual cycle at 115E

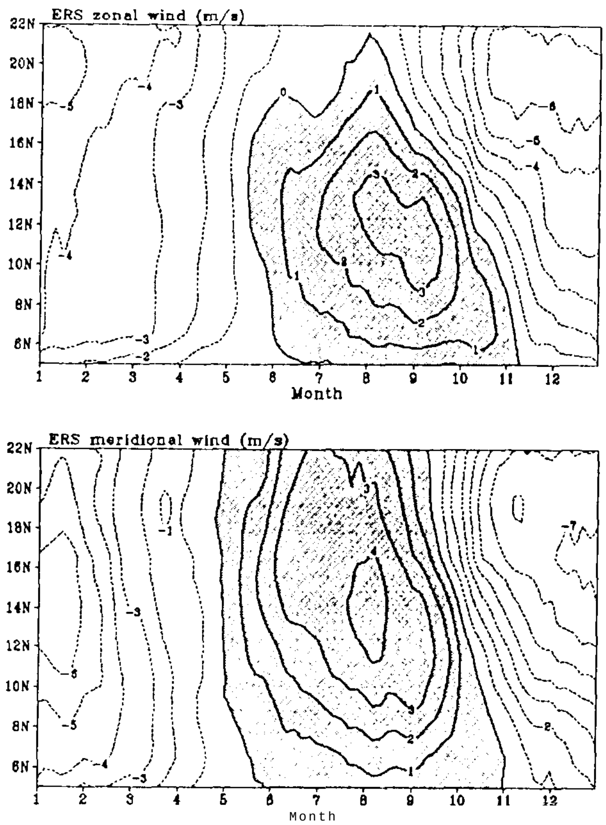

Figure 2: Time-latitude variations along 115°E (in the South China Sea) of annual cycle of (top) zonal wind component and (bottom) meridional wind component derived from five years (1992-1996) of ERS scatterometer data,

Annual cycle at 115E

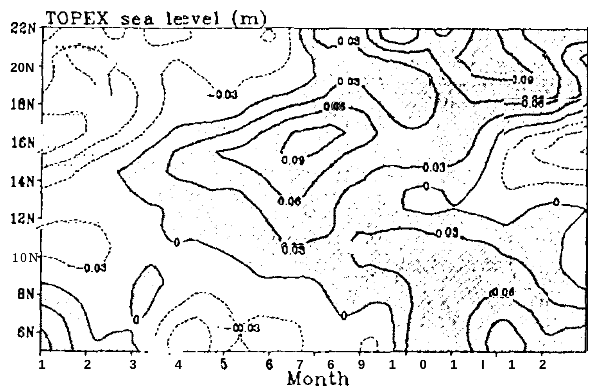

Figure 3: Time-latitude variations along 115°E (in the South China Sea) of the annual cycle of the sea level variation derived from roughly five years (1992-1997) of Topex/Poseidon altimeter data.

4. INTERANNUAL VARIATION

With the annual cycle described in Section 3 removed, the interannual anomalies of the two components of wind and sea level variation were also examined (not shown) . Positive anomalies in both component in summer can be interpreted as anomalous strengthening of the summer monsoon and negative anomalies in both components in winter implies strengthening of winter monsoon, while negative anomalies in summer and positive anomalies in winter may be interpreted as anomalous weakening of the monsoon. According to such interpretation, the scatterometer wind data reveal a prolonged period of enhanced monsoon circulation between the summer of 1992 and the winter of 1994/1995, which roughly coincide with a prolonged period of anomalous warming in the central and eastern equatorial Pacific. The interannual anomalies of sea level changes also implied three periods, from mid-1993 to mid-1994, from end of 1994 to end of 1995, from spring of 1996 through summer of 1997, of enhanced anticyclonic geostrophic current, divided by shorter period of enhanced cyclonic circulation.

5. CONCLUSION

A combination of spacebased data reveals the seasonal changes of the monsoon over the SCS and its interannual anomalies. The onset of winter monsoon, as reflected in the change of surface wind, is found to be clearer and more abrupt than the onset of the summer monsoon. The time of winter monsoon onset occurs earlier in the north but, during spring, the change of surface winds occurs almost simultaneously for the whole basin. The surface winds during summer are frequently interrupted by intra-seasonal activities while the surface winds during winter are more steady. The seasonal change of monsoon is found to cause a reversal of the ocean circulation, from a anticyclonic gyre in summer to a cyclonic gyre in winter. The seasonal change of surface winds is accompanied by coincident change in sea surface temperatures and atmospheric precipitable water. Considerable interannual anomalies are also found in these parameters. The global coverage provided by spaceborne sensors would help to reveal the remote causes of the interannual variabilities in the future.

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